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Assessment of ORYZA-based rice models under organic fertilizer management

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ABSTRACT

Environmental issues associated with intensive agriculture lead to more interests in organic agriculture which is one of sustainable agriculture practices. Organic farms would benefit from the model that simulates soil nutrient dynamics as well as crop growth, which would be useful to optimize the fertilizer application. Few studies have been conducted to simulate crop growth using organic fertilizer, especially for rice which would be an important staple crop. The objectives of this study were to integrate a simple soil nutrient model into the ORYZA 2000 model and to compare with the ORYZA (v3) model under the organic fertilizer application. Crop growth and yield data were obtained at an experiment farm in National Institute of Agricultural Science (NAS) from 2015 to 2017. Another set of rice yield data were obtained at a commercial farm in Suncheon from 2015 to 2016. These data were used to compare estimates of crop yield. Parameter values for both ORYZA 2000 model and ORYZA (v3) model were determined to represent actual crop management and field condition. ORYZA 2000 model tended to have more reliable estimates of crop yield than the ORYZA (v3) model. Both models had relatively large errors in estimating soil inorganic nitrogen. These models also underestimated nitrogen uptake and crop biomass, especially during late vegetative stage and reproductive stage. Nevertheless, the ORYZA 2000 model had greater degree of agreement statistics and less error in rice yield estimation than the ORYZA (v3) model. It appeared that estimation error of crop yield resulted from inaccurate estimation of soil inorganic nitrogen, which would be caused by uncertainties of soil parameters. Weather data measured at a distant weather station to the commercial farm could cause considerable uncertainty in estimation rice yield.

Keywords: Organic fertilizer, Mineralization, ORYZA 2000, ORYZA (v3)

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Introduction

Environmental issues associated with intensive agriculture lead to more interests in sustainable agriculture (Dasgupta et al., 2007, Pretty, 2008). For example, total agricultural area has decreased by 5 million km2 in 2010s whereas areas of organic farming increased gradually to 0.4 million km2 in 2014, which account for 1% of total agriculture area (Willer and Lernoud, 2016). Accordingly, the number of countries where organic farming has been practiced and the number of organic farms has increased.

In general, it would be challenging to manage organic fertilizer application in terms of timing, amount, and type of fertilizer application. For example, nitrogen included in organic fertilizer should be mineralized before the crop begin to uptake this organic nitrogen. Still, the rate of mineralization would depend on abiotic conditions, e.g., weather and soil properties, as well as biotic conditions, e.g., composition and amount of soil microorganisms. Thus, organic fertilizer could result in nutrient deficiency at early stage of crop establishment, which would result in lower yield compared with conventional farming (De Ponti et al., 2012, Chen, 2006).

Organic farms would benefit from a decision support system for fertilizer application. Such a system would help growers make reasonable decision on application of organic fertilizer that have considerable variability in its content. The decision support system would take into account the rate of decomposition of organic matter in soil under a given weather and soil condition as well as the characteristics of organic fertilizers. including nitrogen and water content and CN ratio.

Soil models that have been used to simulate dynamics of soil nutrients could be used to decision making on application of organic fertilizer. For example, RothC and ECOSSE models have been used to simulate daily rate of C and N changes in soil organic matters (Peltoniemi et al., 2007). Crop components are often included in soil models. For example, DNDC and DAYCENT depends on crop modules to estimate uptaken N from soil by crops (Li et al., 1994). However, those models tended to have a simple representation of crop growth, which would make it challenging to estimate dynamics of plant growth, e.g., LAI, dry matter by organs.

Crop growth models have been used the daily growth of various crops including rice (Li et al., 1994, Zhang et al., 2002). For example, the ORYZA 2000 model has been used for rice growth simulation under a limited nitrogen conditions (Lee et al., 2015). The latest development of crop model often focused on improvement of soil modules that allow simulation of the fate of nutrients in soil. For example, ORYZA V3 model has been developed adding more rigorous soil modules to simulate the temporal decomposition rate of soil organic matter. The ORYZA model was also incorporated into the DSSAT model, which provide soil modules for simulation of soil organic matter (de Souza. et al., 2013). In addition, Shin et al. (2015, 2016) reported a simple soil nutrient model, which could be added to the existing ORYZA 2000 model to improve simulation of mineralization of soil organic matter.

Considerable efforts have been made to simulate crop productivity under a given condition of organic fertilizer application (Tuomisto et al., 2012, De Ponti et al., 2012). Still, little attention was given for growth simulation of rice using organic fertilizer although rice would be an important staple crop and effective management of soil organic matter could contribute to minimization of greenhouse emission. The objectives of this present study were to integrate a simple soil nutrient model into the ORYZA 2000 model and to compare rice growth models based on the ORYZA 2000 model under the condition of organic fertilizer application. At first, we describe characteristics of rice growth models derived from the ORYZA 2000 model, and implementation of model based on ORYZA 2000 and a simple soil nutrient models. The performances of those models were illustrated using quantitative results obtained from field experiments at five site-years.

Materials and Methods

1. Crop models

1.1. The ORYZA 2000 model

The ORYZA 2000 model, which was developed by International Rice Research Institute (IRRI) and Wageningen University, has been used to simulate growth and development of rice. The model requires input data to characterize weather, soil, management, and crop. The model can simulate crop growth under potential, water limited, and nitrogen limited conditions. A detailed description on the ORYZA 2000 model is provided in Bouman et al. (2001).

1.2. The ORYZA 2000 model with nitrogen decomposition

van Oort et al. (2015) improved the ORYZA 2000 model modifying functions to simulate include phenology, spikelet formation, and sterility. Still, no soil nitrogen function has not been changed. In this study, an empirical soil nitrogen function suggested by Shin et al. (2016) was added to the original version of the ORYZA 2000 model in order to allow simulation of decomposition process of organic fertilizers as follows:

$$\frac{\mathrm{dN}}{\mathrm{dt}} = k\ (N_p - N) \text{ (Eq. 1)}$$

where N is the total amount of mineralized nitrogen, Np is the potential amount of organic nitrogen that can be mineralized, and k is the relative mineralization rate.

Np is calculated by the CN ratio of the organic fertilizer and k is calculated by the temperature. Shin et al. (2016) suggested that the k values would be useful for the temperature range from 20^{o}C to 30^{o}C. For lower temperature conditions, the Arrhenius relation suggested by Van et al. (1997) was used to estimate k values.

1.3. ORYZA (v3) model

The ORYZA (v3) model is the latest version to improve the ORYZA 2000 model (Li et al., 2017). New modules were developed and integrated and old modules were modified to achieve additional functions, such as interaction of water and nitrogen, soil temperature, daily carbon and nitrogen dynamics (Yuan et al., 2017). Both models depend on the same set of input data although the ORYZA (v3) model requires additional sets of soil parameters.

2. Field experiment

Field experiments were conducted to obtain observation data for validation of crop models. The late maturity cultivar Sindongjin was grown at an experiment farm (35.827N, 127.047E) in National Institute of Agricultural Science (NAS) of Rural Development Administration from 2015-2017. Inorganic soil nitrogen, nitrogen uptake, crop growth and grain yield were measured by crop growth stage. For fertilizer treatment, conventional chemical fertilizer, manure, oilcake, hairy vetch, and rye were used. Application rate for each organic fertilizer was set to be 11 kg

N / 10a, which is a recommended fertilizer application rates in 2000s. inorganic nitrogen content, organic nitrogen, organic carbon was measured to assess an initial condition for the field before transplanting. Soil texture and bulk density were derived from properties of Incheong soil series (Table 3).

Table 1. Crop management settings for NAS field.

Year	Cultivar	Transplanting	Planting density	Leaf number at Transplanting
2015	Sindongjin	6/11	15.15	4
2016		6/14	15.15	4.4
2017		6/14	20	-

Table 2. Properties and application amount of organic fertilizers.

Year	Treatment	N content (%)	Water content (%)	C/N ratio	Application (kg/10a)
2015	Compost	1.4	50.3	24.0	1581
	Oilcake	5.2	16.2	6.2	252
	Hairy vetch	2.7	76.4	16.5	1726
	Rye	1.4	72.7	32.5	2878
2016	Compost	2.1	45.6	15.8	952
	Oilcake	4.6	8.2	9.0	263
	Hairy vetch	2.9	76.3	8.4	1609
	Rye	0.4	68.4	65.3	7723
2017	Compost	1.5	50.5	22.3	1790
	Oilcake	4.7	7.9	8.4	270
	Hairy vetch	3.1	77.7	14.2	1768
	Rye, Oilcake	0.5, 4.7	46.9, 7.9	87.7, 8.4	410, 266

Table 3. Soil properties of experimental field of NAS.

Depth (cm)	Clay (%)	Sand (%)	Org C (%)	Org N (%)	BD (g/cm3)	nh4 (ppm)	no3 (ppm)
0~20	23.60	44.00	1.05	0.11	1.21	1.207	1.287
20~40	23.60	44.00	0.91	0.10	1.21	1.641	1.473
40~60	25.40	36.20	0.73	0.08	1.65	2.493	1.111

3. Experiment for validation

Another set of validation data were obtained at a commercial farm in a Large Area Eco-Friendly Agriculture Complex in Suncheon (34.843N, 127.418E). The late maturity cultivar Haepum was grown from 2015 to 2017 to obtain crop yield (Choi and Jung, 2016). rice seedling was transplanted in early June. Planting density was 30 cm by 15 cm. A commercial organic fertilizer was used. The fertilizer was provided by a local store of Nonghyup (Table 4).

Soil organic nitrogen and soil organic carbon was measured by soil layer to determine an initial condition of a field before transplanting (Table 5). The amount of NH_4^+ and NO_3^- was set to be 0.5% and 0.25%, respectively. Other soil properties including soil texture and bulk density were derived from typical properties of Anryong series.

Table 4. Properties and application amount of organic fertilizers used in Suncheon field.

	N content (%)	Water content (%)	C/N ratio	Application (kg/10a)
Compost	3.93	26.4	11.1	300

Table 5. Soil properties of experimental field of Suncheon.

Depth (cm)	Clay (%)	Sand (%)	Org C (%)	Org N (%)	BD (g/cm3)	nh4 (ppm)	no3 (ppm)
0~22	24.1	20.8	1.06	0.10	1.25	4.82	2.41
22~35	30.1	20.9	0.77	0.07	1.22	3.50	1.75
35~55	27.1	19.2	0.31	0.03	1.39	1.41	0.70

4. Preparation of input files

Input data to the ORYZA models were prepared using observations and literatures. Measurements of sunshine duration was used to estimate solar radiation. The ORYZA models requires coefficients for the Angstrom-Prescott model. Hyun and Kim (2016) reported that the values of 0.18 and 0.55 for those coefficients would result in a reliable estimate of solar radiation. For the experiment farm, weather data were a weather station at NAS, which is operated by agricultural weather data service. Distance between the weather station and the farm was 230m. Weather data for the commercial farm was obtained using WiseDownloader suggested by Lee et al (2015). The weather station, which was about 2 km away from the commercial farm, was operated by Korea Meteorological Administration.

Soil input parameters were obtained from Korean Soil Information System. These parameters were determined by depth to characterize soil properties such as soil depth, clay and sand content, organic matter content, inorganic nitrogen content. Soil parameters associated with hydraulic properties including infiltration rate, van Genuchten parameters were also determined using utilities provided by the ORYZA (v3) model. This tool is based on instantaneous profile method suggested by Watson (1966).

Input parameter for crop management was determined to represent management options common in Korea. Because irrigation is usually used in most paddy fields, a potential condition was applied to the water management option. The impact of a fertilizer on crop growth was simulated by organic fertilizer, the nitrogen condition was set to be limited. Amount of organic nitrogen and carbon in the organic fertilizer was calculated to determine values of SORGANC and SORGANN, which represent surface organic carbon and nitrogen content at the beginning of a season. The timing of organic fertilizer application for the ORYZA 2000 model was set using the date of fertilizer application for field experiments. In contrast, the fertilizer application date for the ORYZA (v3) model was set to be the first date of simulation because no option was available to specify the application date.

The date of transplanting was set to be the same date as the transplanting date for the field experiments. The ORYZA 2000 model and the ORYZA (v3) model had different algorithm to estimate temperature from the sowing date to the transplanting date for growing a seedling (Appendix A). Sowing date was adjusted for a seedling to have four leaves at the timing of transplanting date. The phyllochron was calculated as Lee et al. (2008) suggested.

The cultivars used in the field experiment were Sindongjin and Haepum, which is mid-late maturity and mid-maturity groups, respectively. Under the assumption that rice growth and yield would be similar between cultivars in the same maturity group (Wikarmpapraharn and Kositsakulchai, 2010), the former and the latter was simulated using cultivar parameters for mid-late and mid-maturity cultivar, respectively.

5. Evaluation of the models

The graphical and statistical analyses were carried out to evaluate the performance of both models to predict the soil nitrogen and crop growth. Considering difference of the decomposition aspects by organic materials, mineralization rate, soil nitrogen, and nitrogen uptake were compared. TNSOIL (the amount of nitrogen that is available for crop uptake from the soil) was used for the ORYZA 2000 model to compare soil nitrogen. Accordingly, crop growth variables for LAI (leaf area index), WAGT (total aboveground weight), WLVG (green leaf weight), WST (stem weight), and WSO (panicle weight) were evaluated, and finally, the yields had compared each other. For each variable, the simulated data of the observed dates were extracted from the daily simulation output. In this study, R^2 (correlation coefficient) of the linear regression, NRMSE (normalized root mean square error, Eq. 2), EF (modeling efficiency, Eq. 3), and d (index of agreement, Eq. 4) between simulation and observation were calculated for each variables (Kim et al., 2012).

$$\mathrm{NRMSE} = \frac{100}{\mathrm{X_i}} \times \sqrt{\frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{n}} \quad \text{(Eq. 2)}$$

$$\mathrm{EF} = 1.0 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2} \quad \text{(Eq. 3)}$$

$$\mathrm{d} = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}(|Y_i - \bar{X}| + |X_i - \bar{X}|)^2} \quad \text{(Eq. 4)}$$

In the equations, n is the number of data pairs, X is the average of the observed data, and X_i and Y_i are the i^{th} pair of observed and simulated data, respectively. The performance of the models would be good when R^2, EF, and d are near 1, and NRMSE is near 0.

Results

1. Weather condition at experiment and validation field

During the growing period of rice (June to October), the sunshine duration was longest at experiment field in 2015, whereas the mean temperature was highest at validation field in 2016 (Table 6). The amount of precipitation was higher at validation field, which increased over years. Even if the mean weather conditions are similar, the seasonal pattern was different (APPENDIX B). For example, vapor pressure was higher in summer and lower in spring and fall of 2017 at the NAS field.

Table 6. Weather condition during June to October. Mean of sunshine duration (Sd), minimum temperature (Tmin), maximum temperature (Tmax), vapor pressure (Vp), wind speed (Wind), and cumulative precipitation was obtained.

Site	Year	Sd	Tmin	Tmax	Vp	Wind	Prcp
NAS	2015	6.4	17.0	26.6	2.1	1.4	433.0
NAS	2016	5.5	18.6	27.3	2.3	1.3	630.5
NAS	2017	5.8	18.0	27.5	2.2	1.1	706.5
Suncheon	2015	5.9	16.0	26.7	2.1	1.3	732.9
Suncheon	2016	5.0	18.5	27.7	2.2	1.3	884.3

2. Soil nitrogen simulation at the experimental field

The rate of mineralization simulated using the ORYZA 2000 model and the ORYZA (v3) model was differ by organic fertilizer although its temporal pattern was similar to each other (Fig. 1). For example, mineralization rate was considerably high after applying organic fertilizer. However, the timing of peak mineralization rate differed by model. For example, the ORYZA 2000 model had the greatest rate of mineralization right after incorporating organic fertilizer. In contrast, the ORYZA (v3) model had the highest rate of mineralization before panicle initiation. After the timing, the mineralization rate decreased gradually. Still, the mineralization rate decrease for the ORYZA 2000 model was faster than that for the ORYZA (v3) model.

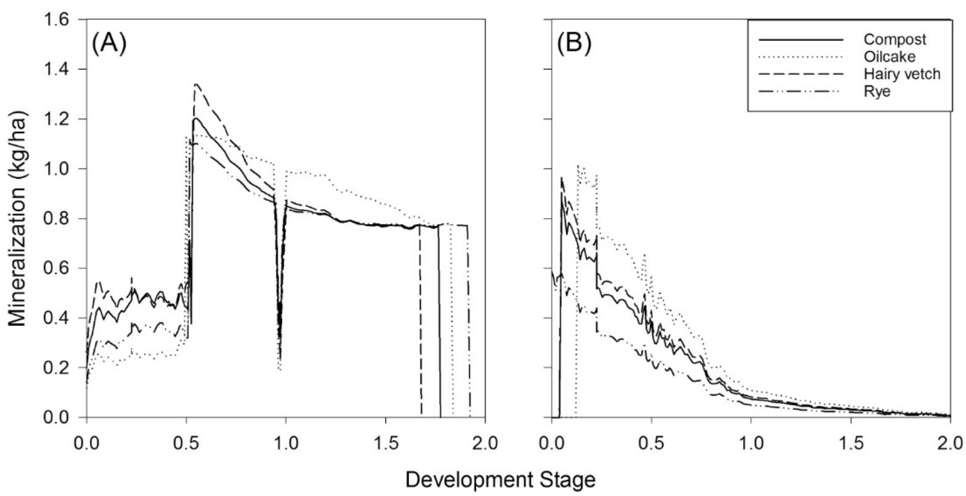

Fig. 1. Daily mineralization rate obtained from (A) the ORYZA (v3) model and (B) the ORYZA 2000 model.

Inorganic nitrogen content in soil remained high until panicle initiation after applying organic fertilizer at the beginning of a season. After the time period, soil nitrogen content decreased to a certain minimum amount over time, which differed by fertilizer and season. The timing of high nitrogen content in soil was simulated reasonably for both ORYZA (v3) and ORYZA 2000 models although the timing of peak nitrogen content was 10-20 days early in simulations. Still, both models failed to estimate accurate amount of soil nitrogen. For example, the ORYZA (v3) model tended to overestimate the maximum amount of inorganic soil nitrogen in 2016. During the late vegetative growth stage, the ORYZA (v3) model had relatively large amount of inorganic soil nitrogen compared with measurements. In contrast, the ORYZA 2000 model underestimated inorganic soil nitrogen in both seasons. In particular, no inorganic soil nitrogen was left when the ORYZA model was used because all of soil nitrogen was uptaken by rice.

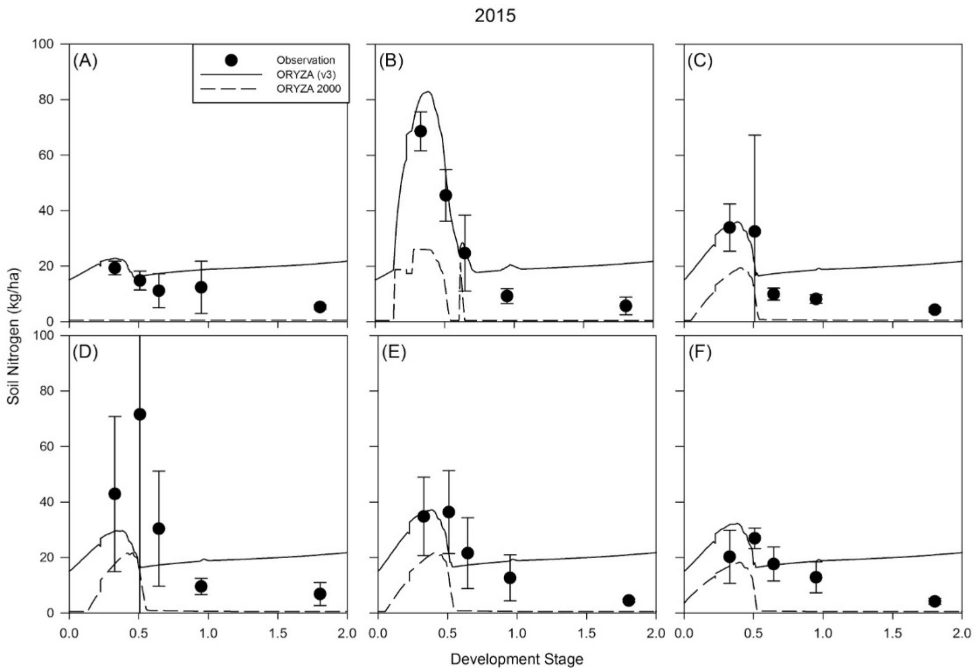

Fig. 2. Time series of inorganic soil nitrogen contents in 2015 after applying (A) no fertilizer, (B) urea, (C) compost, (D) oilcake, (E) hairy vetch, and (F) rye, respectively.

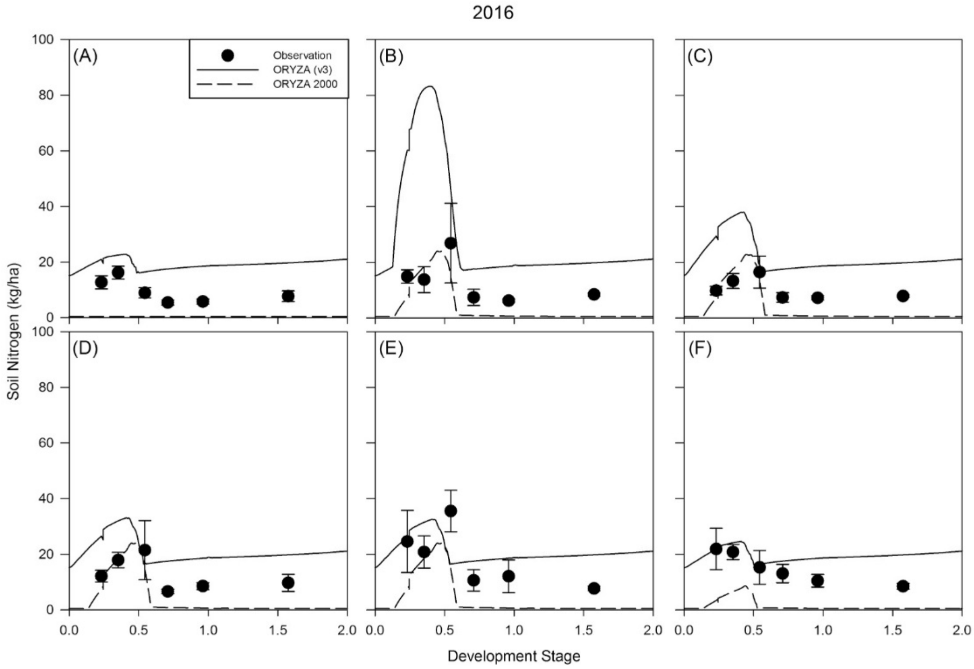

Fig. 3. Time series of inorganic soil nitrogen content in 2016 after applying (A) no fertilizer, (B) urea, (C) compost, (D) oilcake, (E) hairy vetch, and (F) rye, respectively.

Temporal pattern of nitrogen uptake slightly differed by organic fertilizer. Overall, the amount of nitrogen uptake in 2015 was relatively similar for urea, oilcake, and hairy vetch. the nitrogen uptake for compost was slightly lower than that for urea, oilcake, and hairy vetch especially during the late vegetative growth stage. In no fertilizer and rye plot, rice has uptaken similar amount of nitrogen. Both ORYZA (v3) and ORYZA 2000 models had reasonable nitrogen uptake before DSV of 0.5. Throughout the late vegetative growth stage and reproductive stage, however, both models failed to estimate increased rate of nitrogen uptake except for harvest periods. The ORYZA (v3) model tended to have less error in estimating nitrogen uptake than the ORYZA 2000 model did over the season. For example, error of the ORYZA (v3) model was about 1 kg/ha for urea and 20 kg/ha for compost, oilcake, and hairy vetch, while error of the ORYZA 2000 model was over than 20kg/ha for those treatments (Fig. 4).

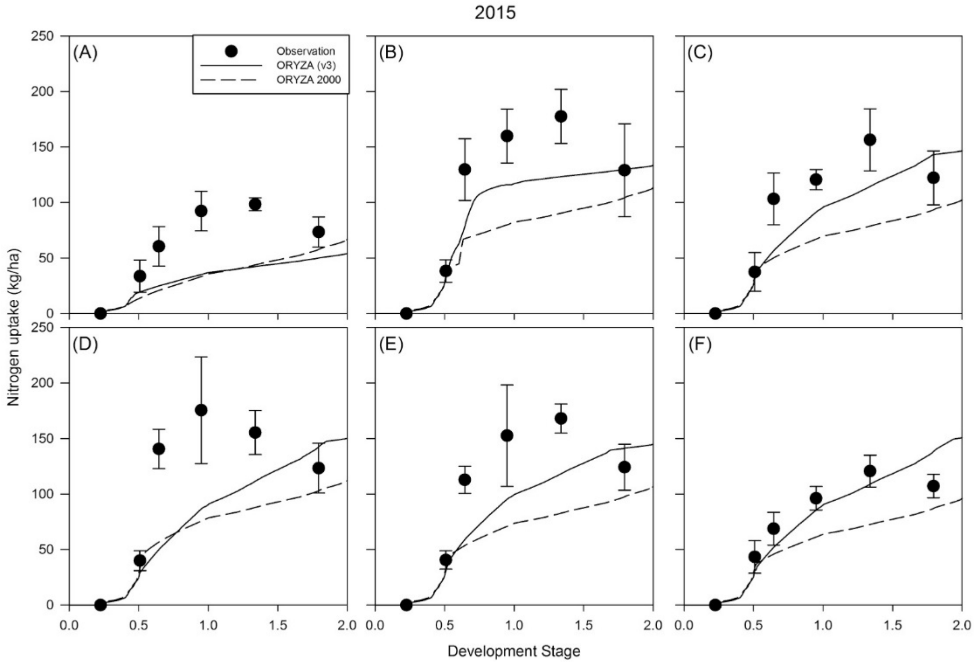

Fig. 4. Daily nitrogen uptake simulated in 2015 after applying (A) no fertilizer, (B) urea, (C) compost, (D) oilcake, (E) hairy vetch, and (F) rye, respectively.

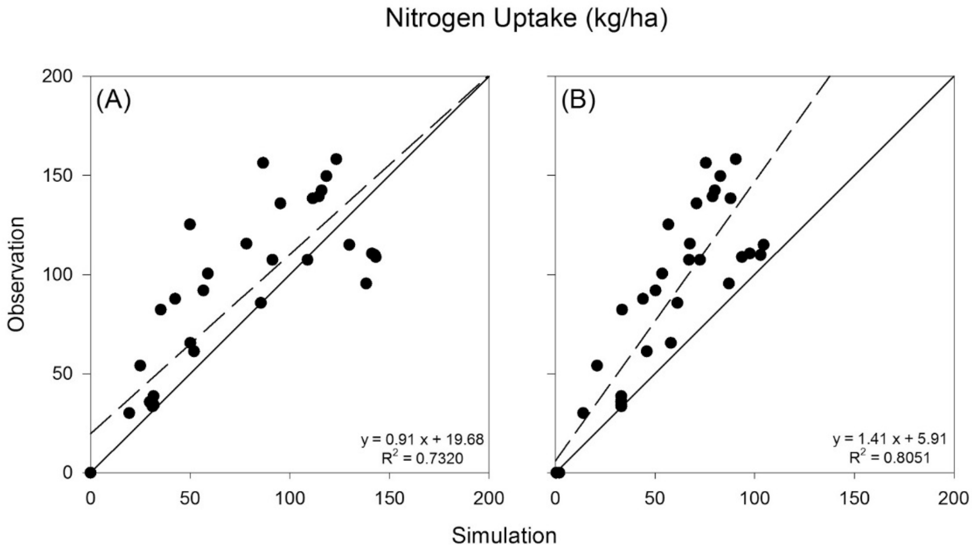

Fig. 5. Scatter plot between simulated and observed nitrogen uptake. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

Table 7. Statistical values for NRMSE, EF, d between simulated and observed values using ORYZA (v3) and ORYZA 2000 models

Variables	N uptake		LAI	
	ORYZA (v3)	ORYZA 2000	ORYZA (v3)	ORYZA 2000
NRMSE	42.1146	54.4630	51.3000	41.4117
EF	0.5659	0.2740	0.4162	0.6196
d	0.8749	0.7666	0.8019	0.8795

3. Crop growth simulation at the experimental field

Although the crop growth was underestimated for both models, the accuracy of the ORYZA 2000 model was higher than the ORYZA (v3) model (Fig. 6-10). For example, d value for LAI was 0.9 for the ORYZA 2000 whereas the value was 0.8 for the ORYZA (v3) model. The effect of the organic fertilizer was greater in observation than simulation (APPENDIX C). For example, it was found that difference of stem weight between hairy vetch and rye plots was about 1000 kg/ha in observed data. In contrast, the ORYZA (v3) model and the ORYZA 2000 model had relatively small difference in stem weight, which was 300 kg/ha, and 150 kg/ha, respectively. The difference between two models was also small in urea plot.

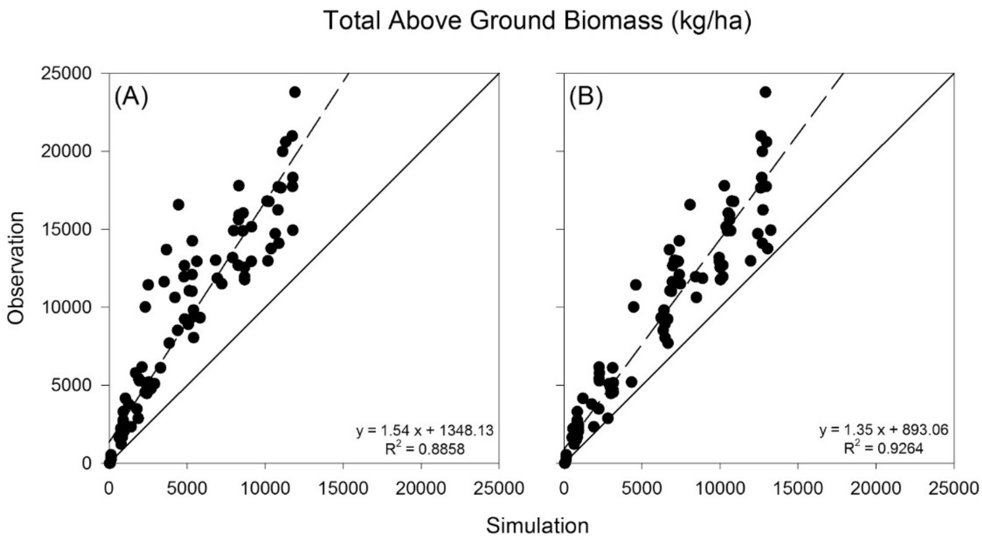

Fig. 6. Scatter plot between simulated and observed total aboveground biomass. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

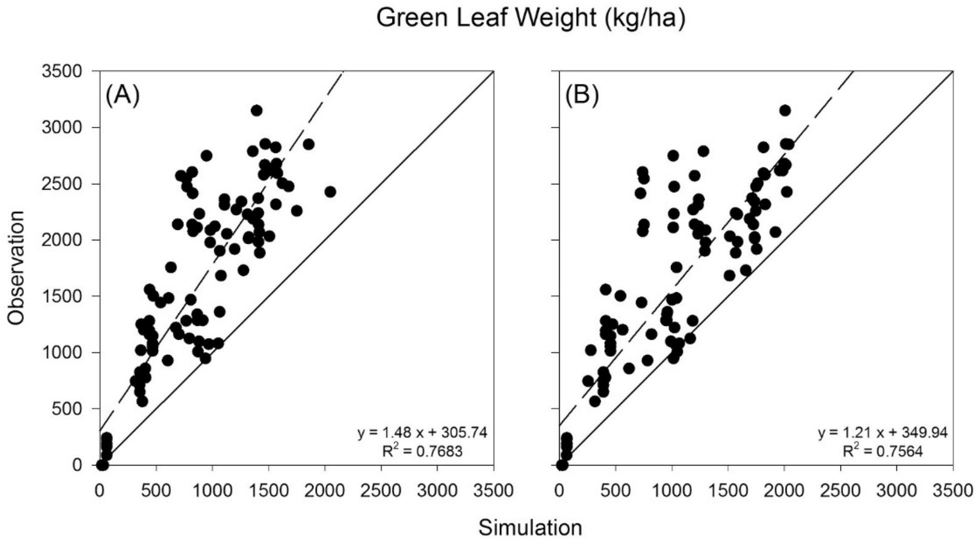

Fig. 7. Scatter plot between simulated and observed green leaf weight. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

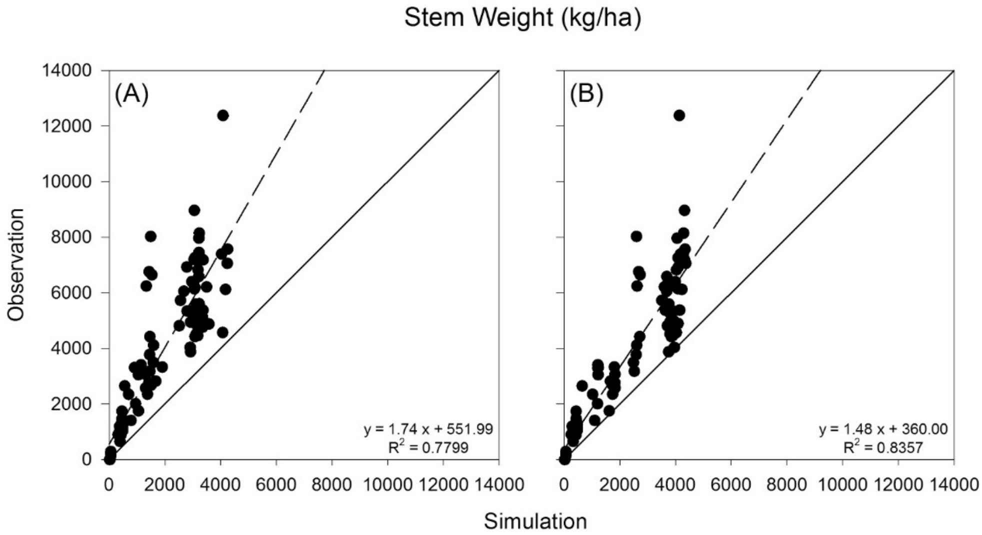

Fig. 8. Scatter plot between simulated and observed stem weight. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

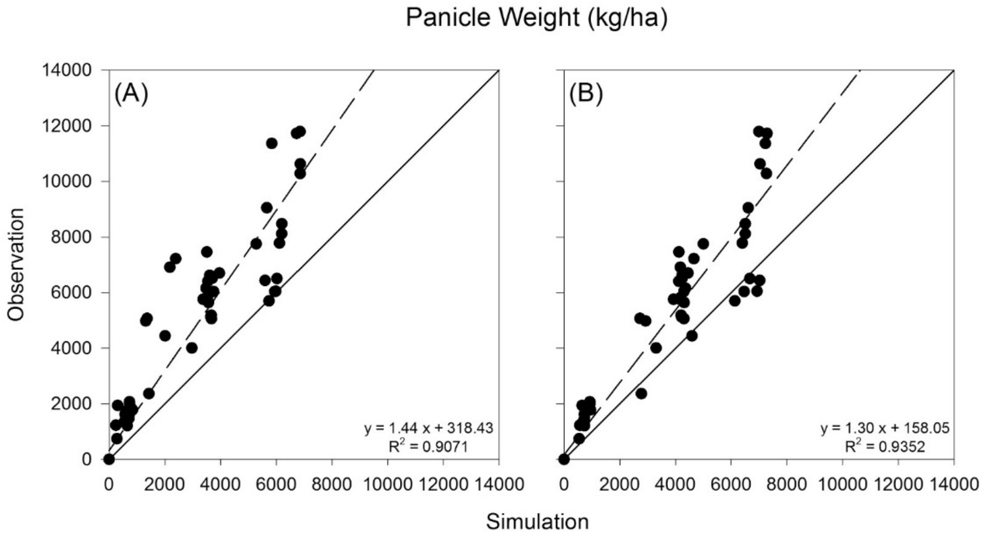

Fig. 9. Scatter plot between simulated and observed panicle weight. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

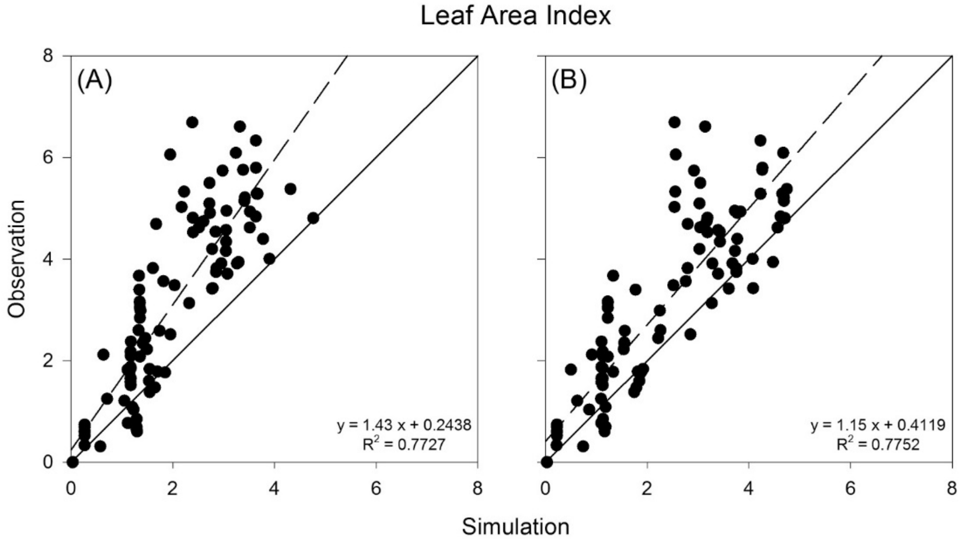

Fig. 10. Scatter plot between simulated and observed leaf area index. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

4. Crop yield estimation at the experimental field

The ORYZA 2000 model had a less error in estimating crop yield although both the ORYZA (v3) and ORYZA 2000 models underestimated rice yield under the condition of organic fertilizer. For example, the NRMSE of ORYZA 2000 model was 14.18 whereas that of the ORYZA (v3) model was 24.44. In part, these errors resulted from a large difference between observation and estimates for no fertilizer treatment, which had the error of about 1000 kg/ha. In 2017, both models failed to estimate sudden yield increase after applying oil cake.

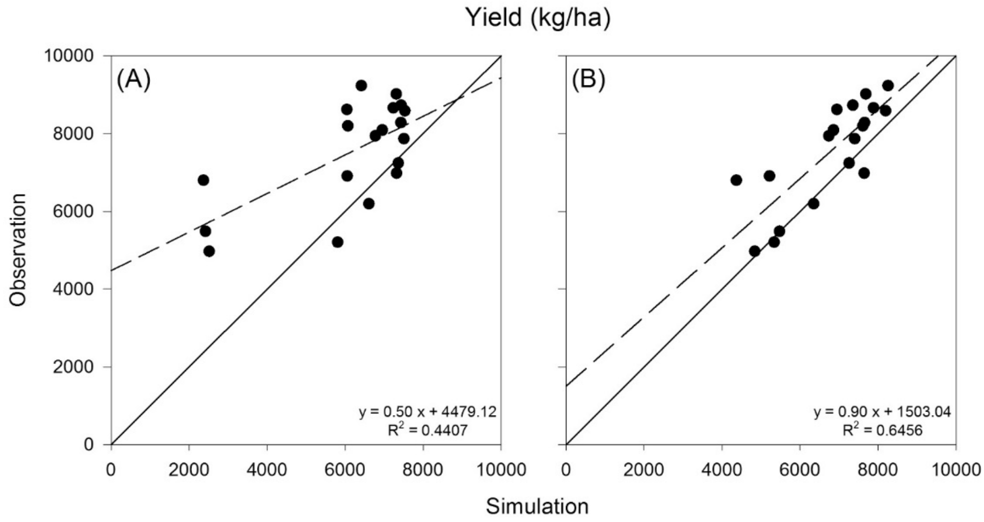

Fig. 11. Scatter plot between simulated and observed yield. (A) for the ORYZA (v3) model and (B) the ORYZA 2000 model.

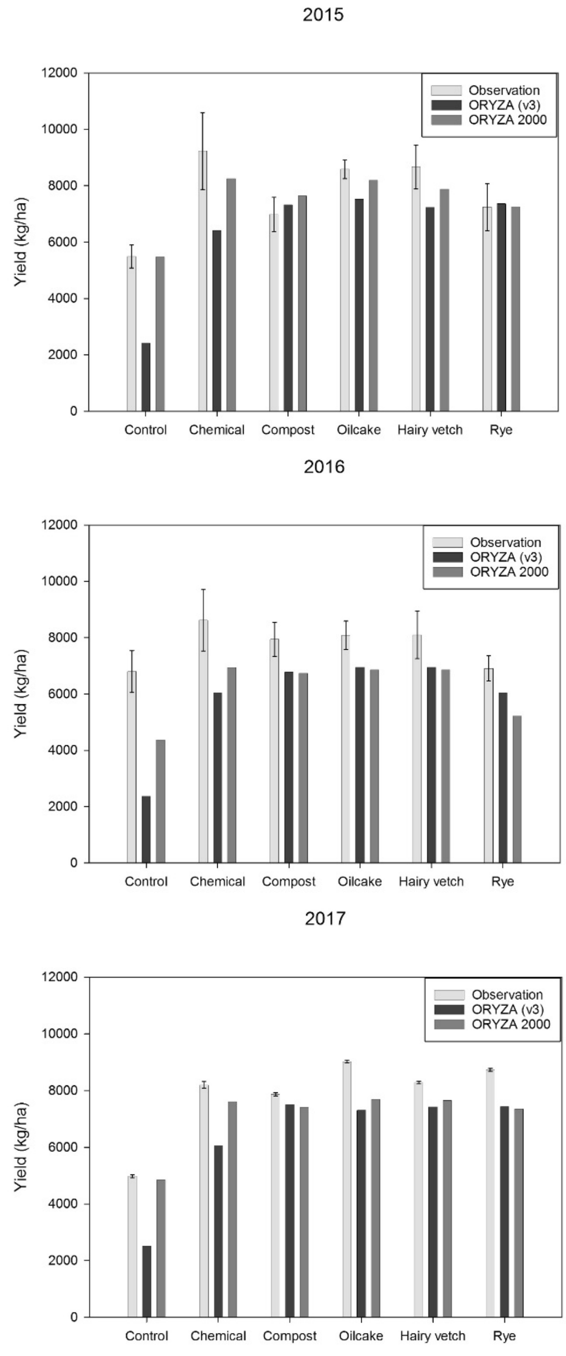

Fig. 12. Comparison between simulated and observed yield at the NAS field.

5. Crop yield estimation at the validation site

Simulated yields for both models were similar to the observed yield at the commercial farm in Suncheon city. The annual variation of yield was reasonably simulated using both models. Estimates of yield was within 10% of observed yield for both models although the ORYZA 2000 model had a less error in crop yield estimation.

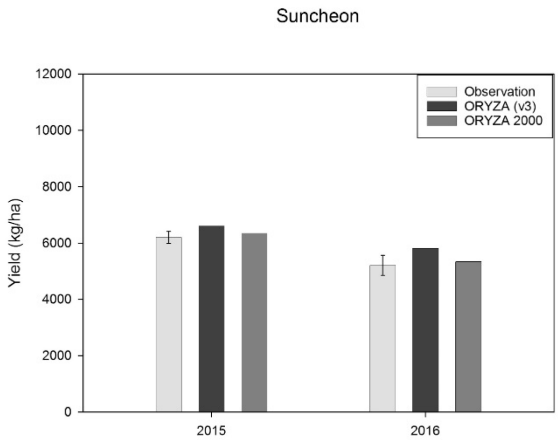

Fig. 13. Comparison between simulated and observed for Suncheon field.

Discussion

1. Soil inorganic nitrogen

The error of the soil inorganic nitrogen for each model resulted from different reasons. In the ORYZA 2000 model, the inorganic nitrogen is calculated for the amount of nitrogen that is available for crop uptake from the soil. For this reason, the inorganic nitrogen keeps 0 except the increase by the fertilizer application (Figs. 2-3). Furthermore, the model cannot take into account the complex nitrogen dynamics in the soil, but simply calculate the soil inorganic nitrogen considering only the increase by fertilizer and the decrease by crop uptake.

On the other hand, the ORYZA (v3) model simulates actual inorganic nitrogen such as NH_4^+, NO_3^-, and soil organic nitrogen content considering the complex nitrogen dynamics including mineralization, initial condition, soil temperature, loss from leaching, and denitrification (Li et al., 2017). Accordingly, input data became more detailed and required more data than ORYZA 2000. In this study, the basic data, such as soil properties, organic matter content, and initial conditions, were obtained, but the detailed data, such as soil temperature, cellulose and carbohydrate contents of the organic fertilizers, were not able to use due to the lack of data.

The mineralization of the ORYZA (v3) was also the cause of the error. The pattern of the mineralization of the ORYZA (V3) was different from existing studies. Giacomini et al. (2015) showed that mineralization rate using sewage sludge and oat straw is fastest right after the application and become slower over incubation time. Van et al. (1997) also showed that maximum mineralization rate appeared the beginning of the incubation at low temperature. ORYZA (v3), however, simulated the peak time of mineralization rate before the panicle initiation period, of which the soil inorganic nitrogen became insufficient due to the nitrogen uptake by crop. Because the timing of application of organic fertilizer is fixed to be the first date of simulation, mineralization rate and total amount would be different by start time of the simulation. These mineralization functions need to be modified to obtain more accurate result.

The Difference of the nitrogen uptake after DVS 0.5 is affected by the soil inorganic nitrogen. As the inorganic nitrogen available for crop uptake was exhausted at that time, the nitrogen uptake depends on mineralization of the organic fertilizers and indigenous soil nitrogen supply. The indigenous supply which is defined as a constant parameter in the ORYZA 2000 model needs to be modified for each experiment, as it is determined by mineralization of soil organic matter and biological nitrogen fixation (Bouman et al., 2001)

2. Crop growth

Underestimation of crop growth was caused by underestimation of the nitrogen uptake for both ORYZA models. The high degree of agreement statistic for the rye field coincide with a small error in nitrogen uptake (Fig. 4, APPENDIX C). It is most likely that lower nitrogen uptake deterred crop growth in simulations using the models. Still, crop growth of the ORYZA (v3) model was lower than that of the ORYZA 2000 model. In particular, the ORYZA (v3) model had greater nitrogen uptake than the ORYZA 2000 model, which suggested that the new modules for the ORYZA (v3) model would require further improvement. In part, recalibration of cultivar parameters would be need for the ORYZA (v3) model.

The differences of crop growth by the types of organic fertilizer would be affected by the mineralization patterns composition of the organic fertilizers that are not expressed by CN ratio (Cabrera et al., 2005). The ORYZA models, however, only consider about CN ratio and nitrogen amount, so that the differences of crop growth by the types of organic fertilizer became small. For example, crop growth and yield were higher in oilcake plot and rye plot that oilcake was additionally added in 2017, while both models could not simulate the great effect of oilcake.

Difference between both models would also be affected by the aspect of mineralization. The crop growths for both models were almost similar in urea treatment, while those were different in organic fertilizer treatments.

Finally, the uncertainties of the input data could result in a relatively large error in crop yield. Hyun and Kim (2017) reported that error of heading date become large as the distance between experiment and weather station location increases. Also, since the soil series data differed from the actual soil, the data from the experimental field would increase the accuracy of the simulation.

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APPENDIX A

When the seedbed temperature is set, ORYZA 2000 raise the maximum temperature, while ORYZA (v3) raise both of the minimum and the maximum temperature (Fig. 1). The difference of the temperature increase affects the phenological development rate that would make the difference of growing periods.

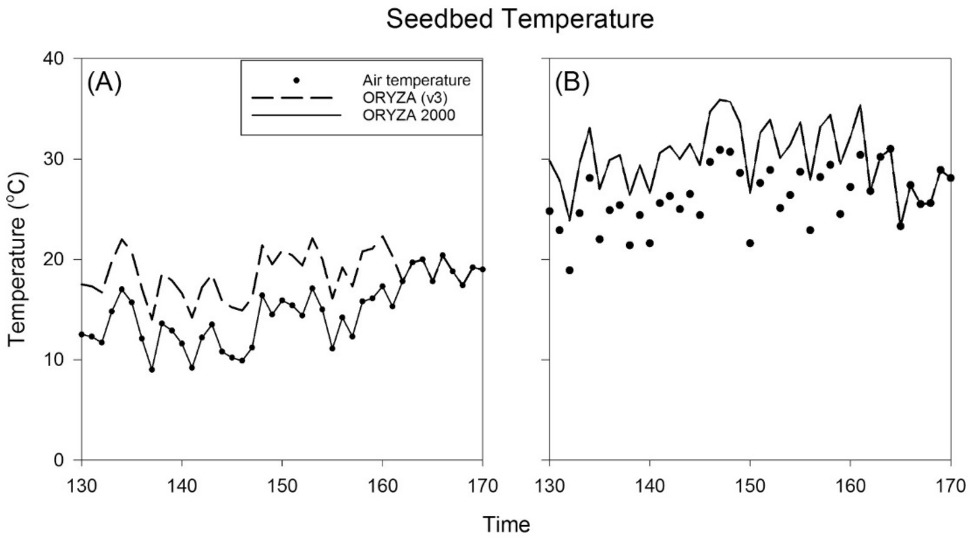
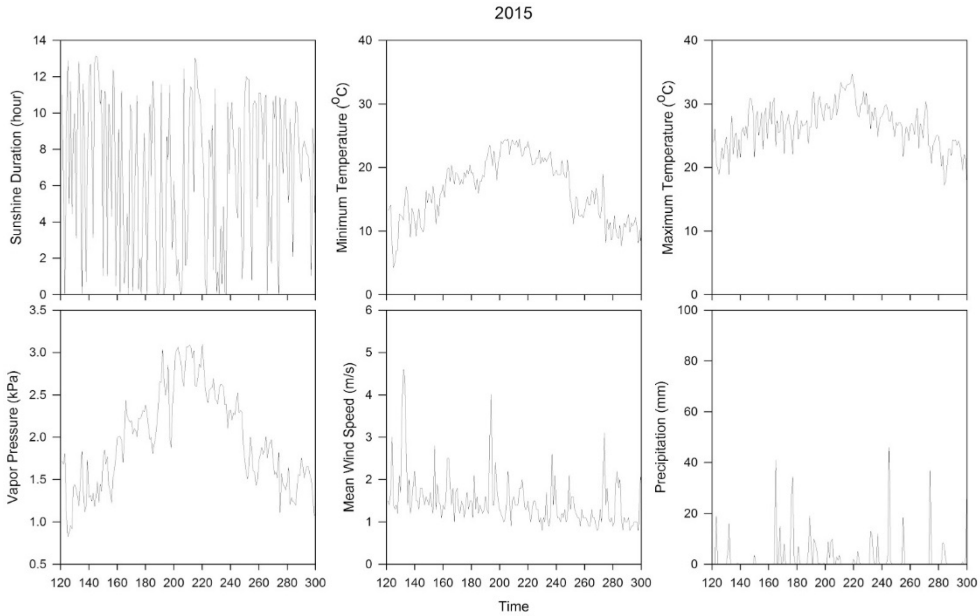
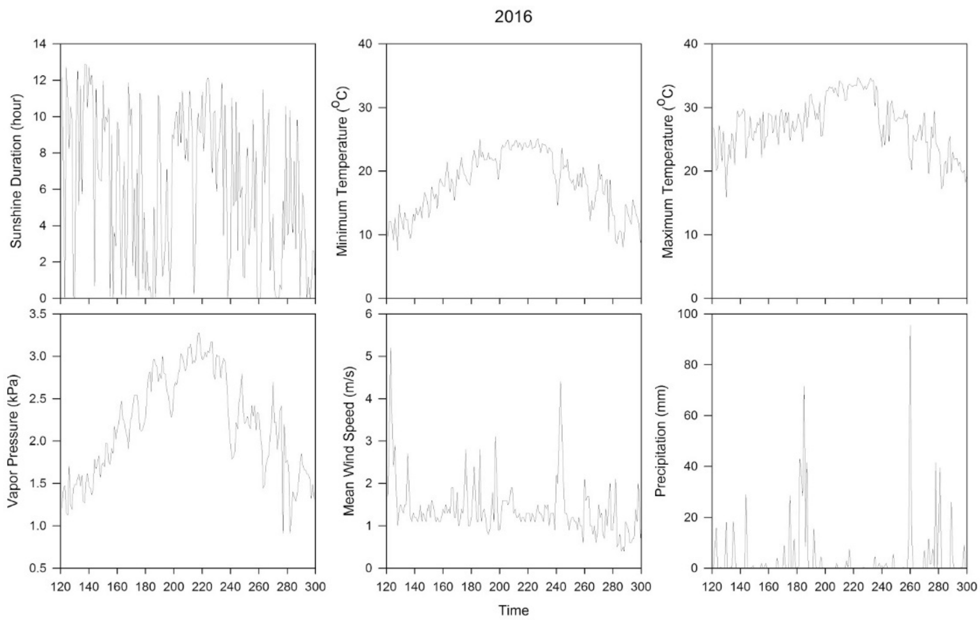


Fig. A1. Minimum temperatures (A) and maximum temperatures (A) during the seedbed stage.

APPENDIX B

Daily weather data include sunshine duration, minimum temperature, maximum temperature, vapor pressure, wind speed and precipitation.





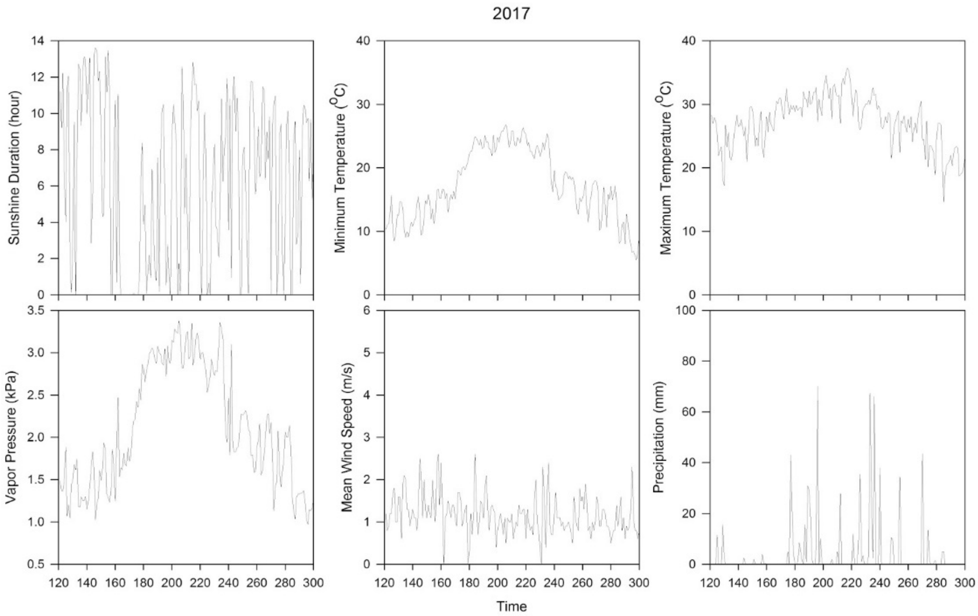


Fig. B1. Daily weather data for NAS field measured from 2015 to 2017.

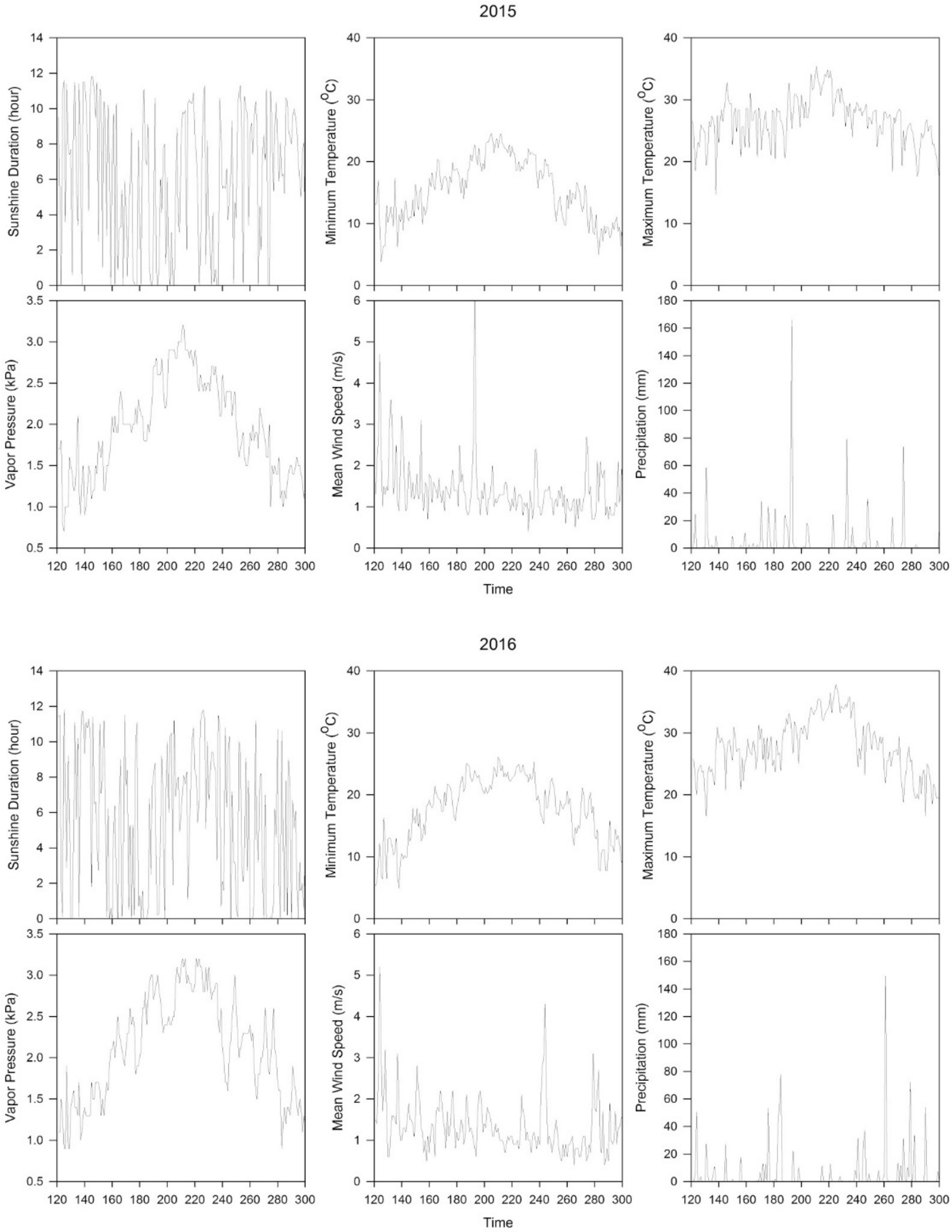
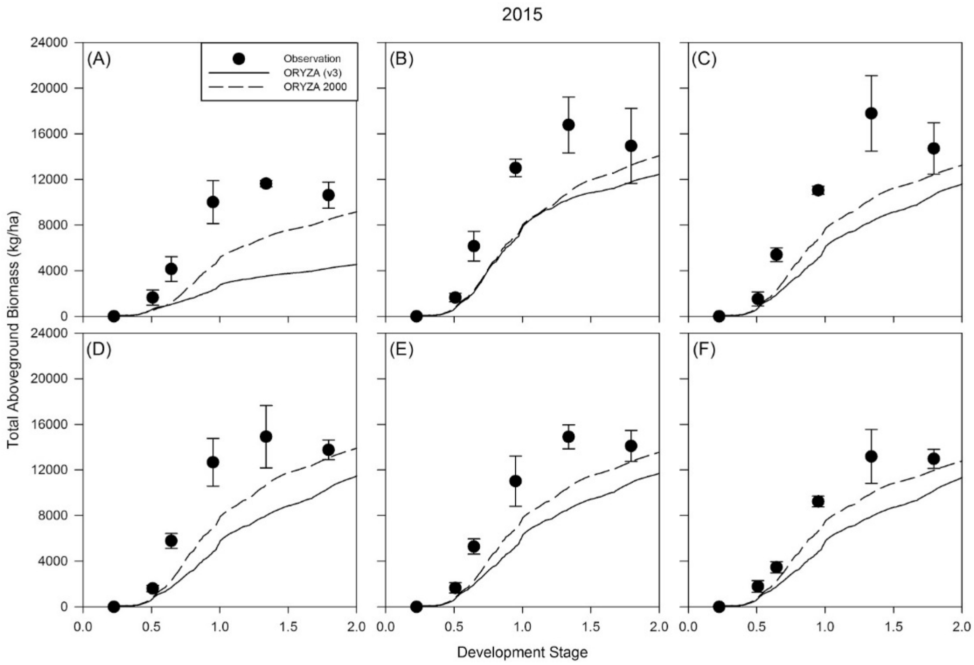


Fig. B2. Daily weather data for Suncheon field in 2015 and 2016.

APPENDIX C

Daily outputs for (A) no fertilizer, (B) urea, (C) compost, (D) oilcake, (E) hairy vetch, and (F) rye, respectively.



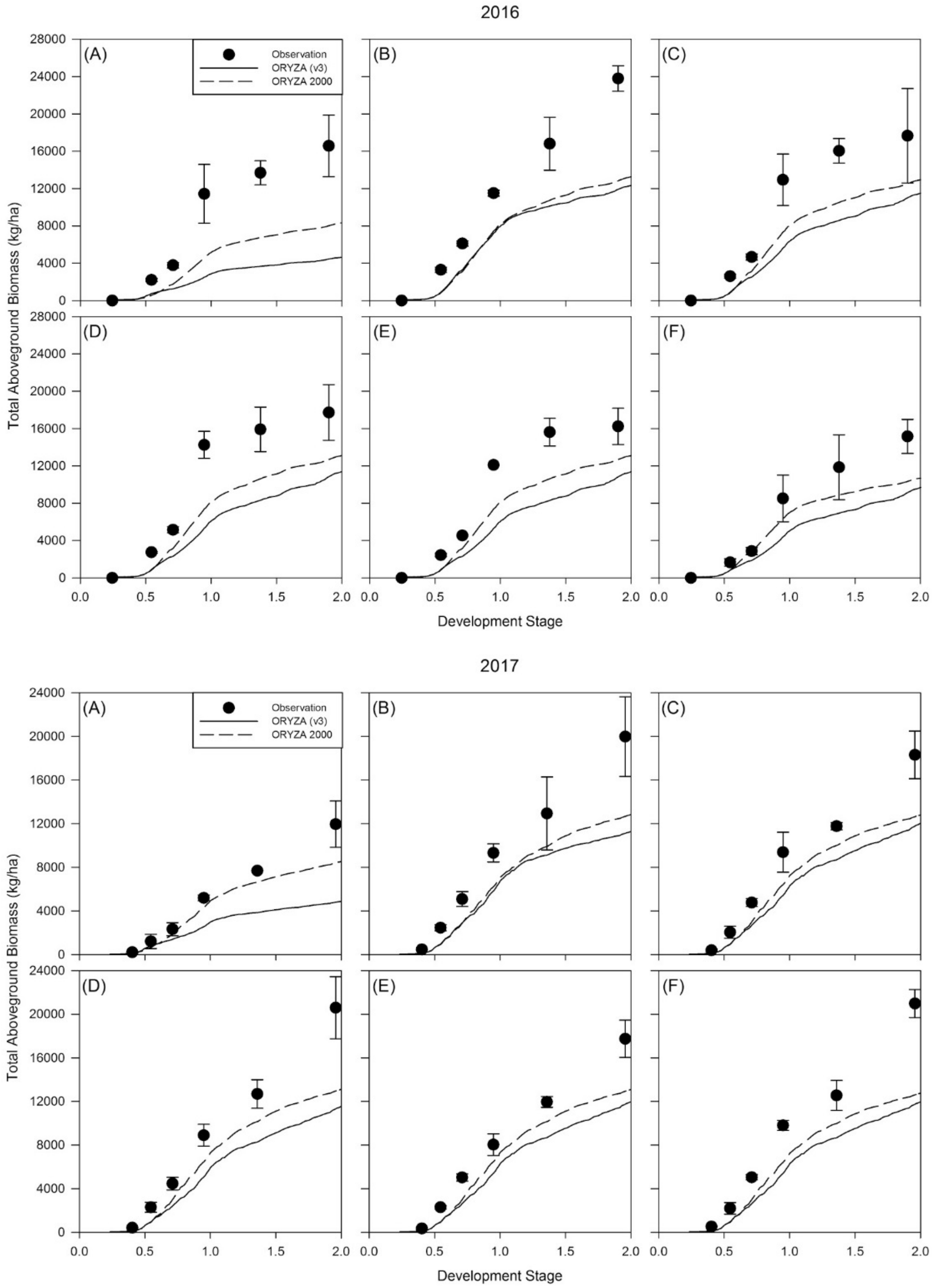
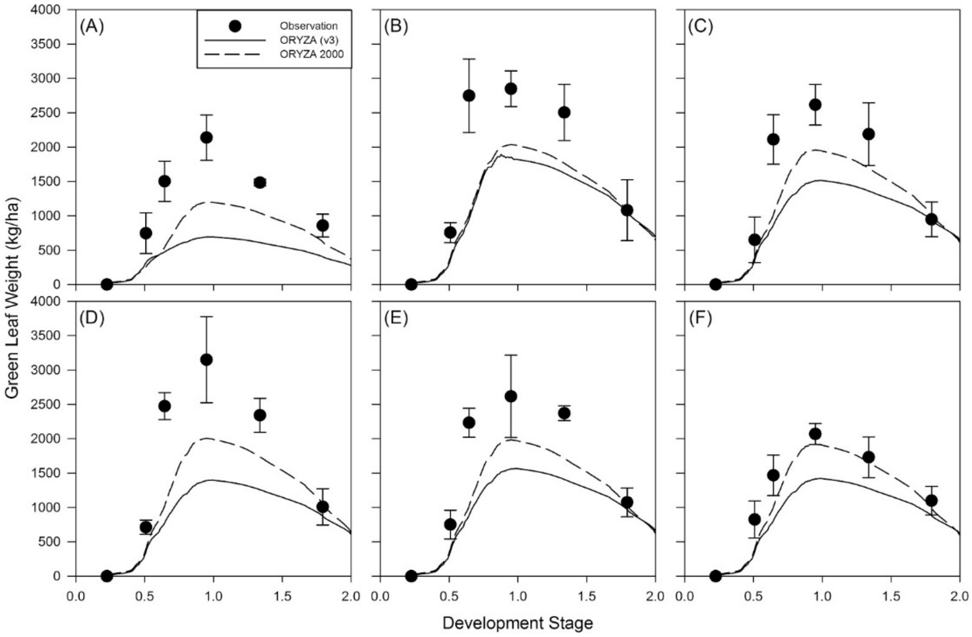
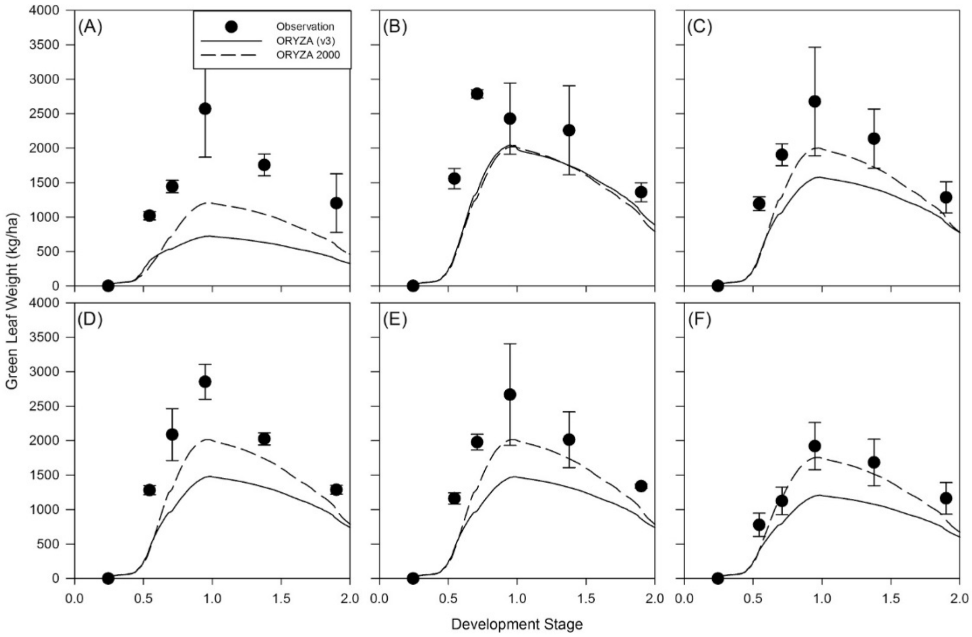


Fig. C1. Daily output of total aboveground biomass from 2015 to 2017.

2015


(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Green Leaf Weight (kg/ha)
Development Stage
0
500
1000
1500
2000
2500
3000
3500
4000
0.0
0.5
1.0
1.5
2.0

2016


(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Green Leaf Weight (kg/ha)
Development Stage
0
500
1000
1500
2000
2500
3000
3500
4000
0.0
0.5
1.0
1.5
2.0

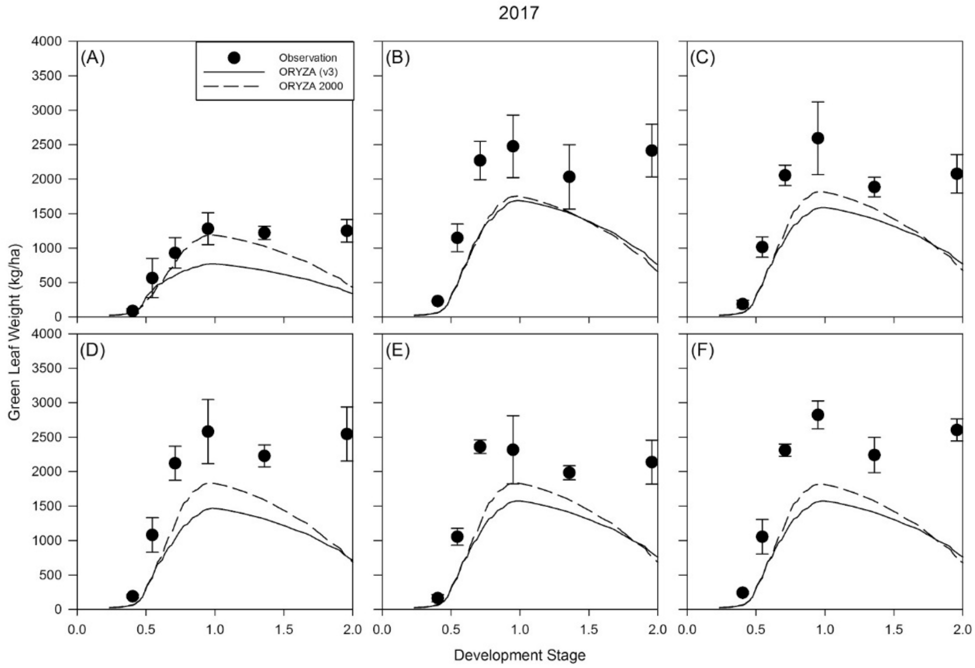
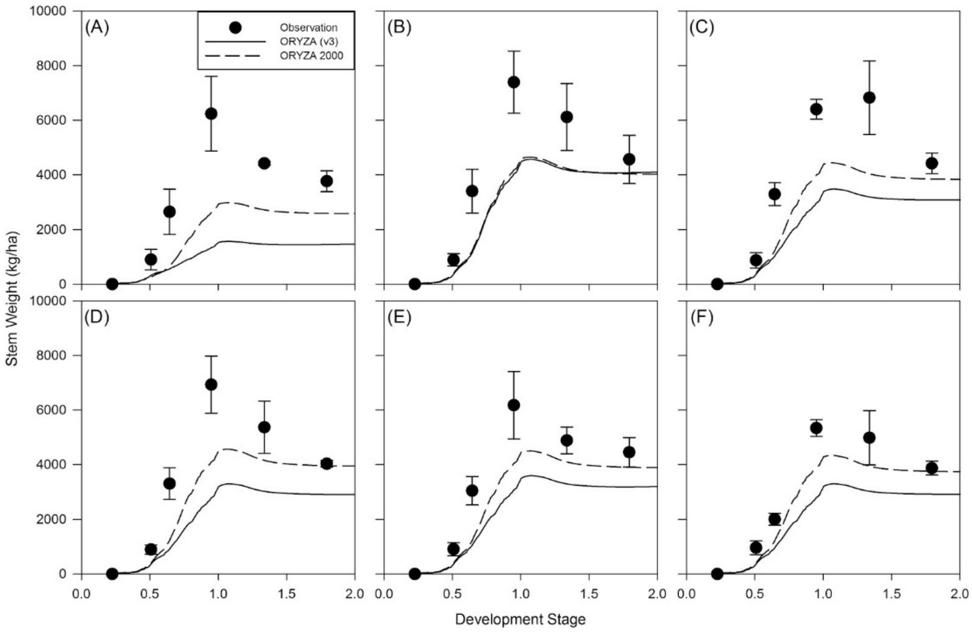
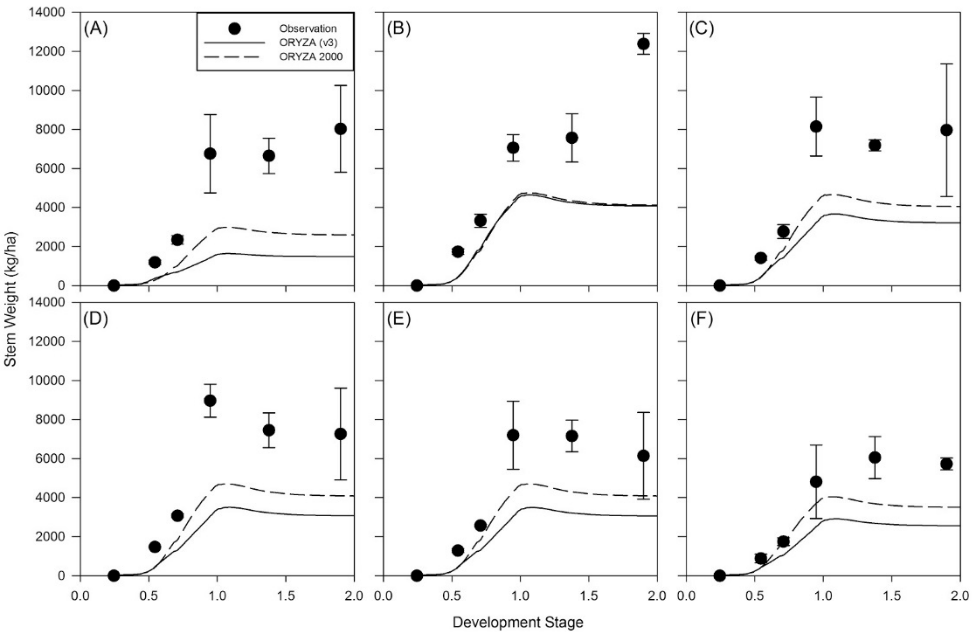


Fig. C2. Daily output of green leaf weight from 2015 to 2017.

2015


(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Stem Weight (kg/ha)
Development Stage

2016


(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Stem Weight (kg/ha)
Development Stage

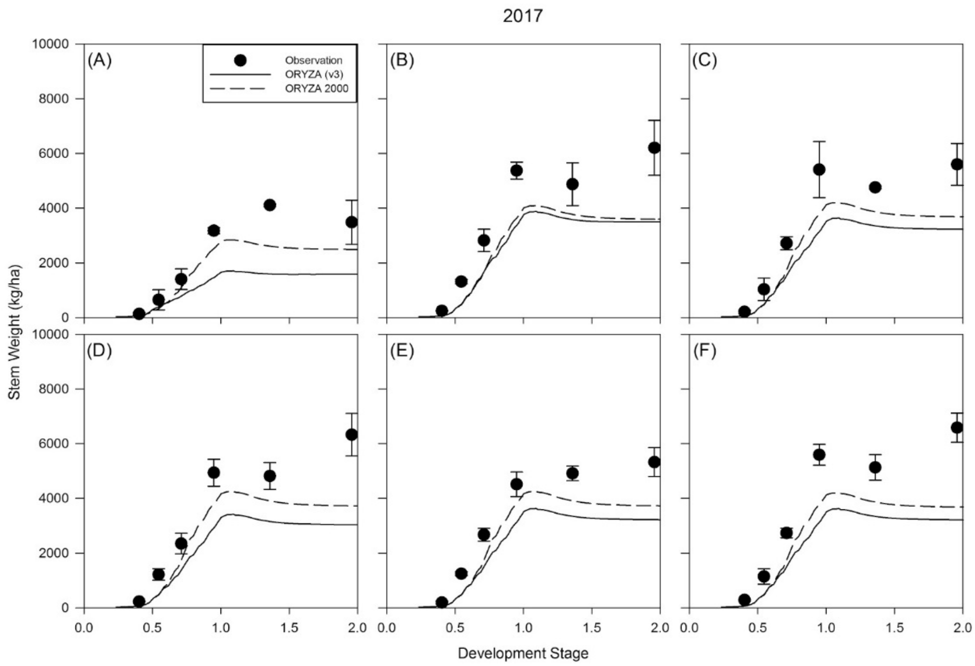
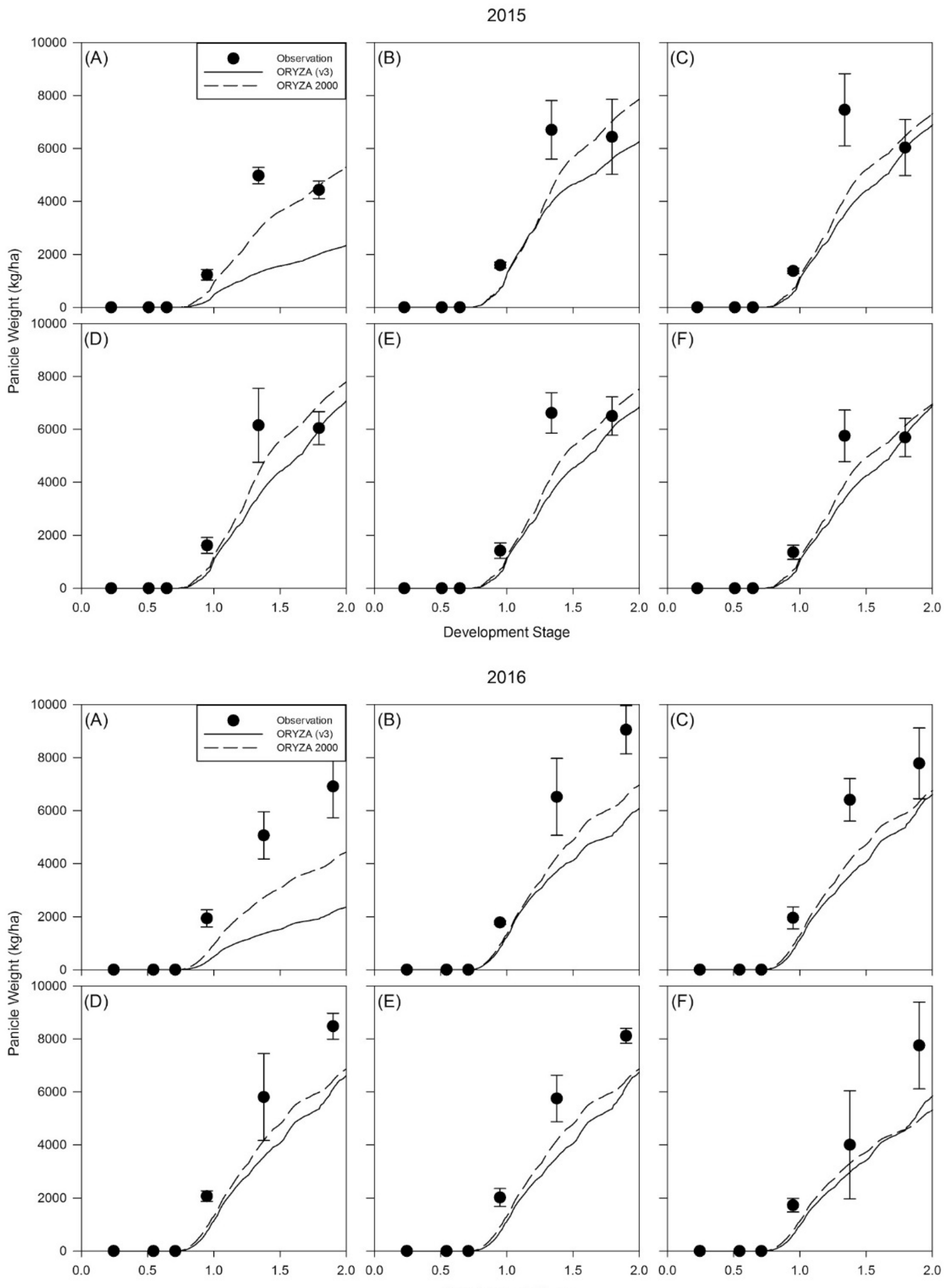


Fig. C3. Daily output of stem weight from 2015 to 2017.


2015
2016
(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Panicle Weight (kg/ha)
Development Stage

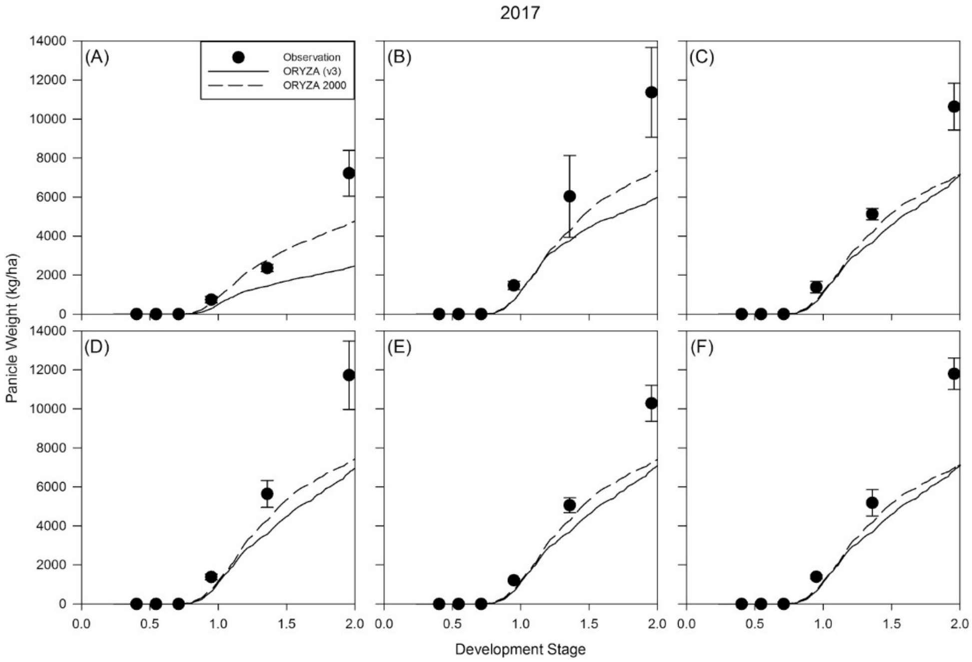
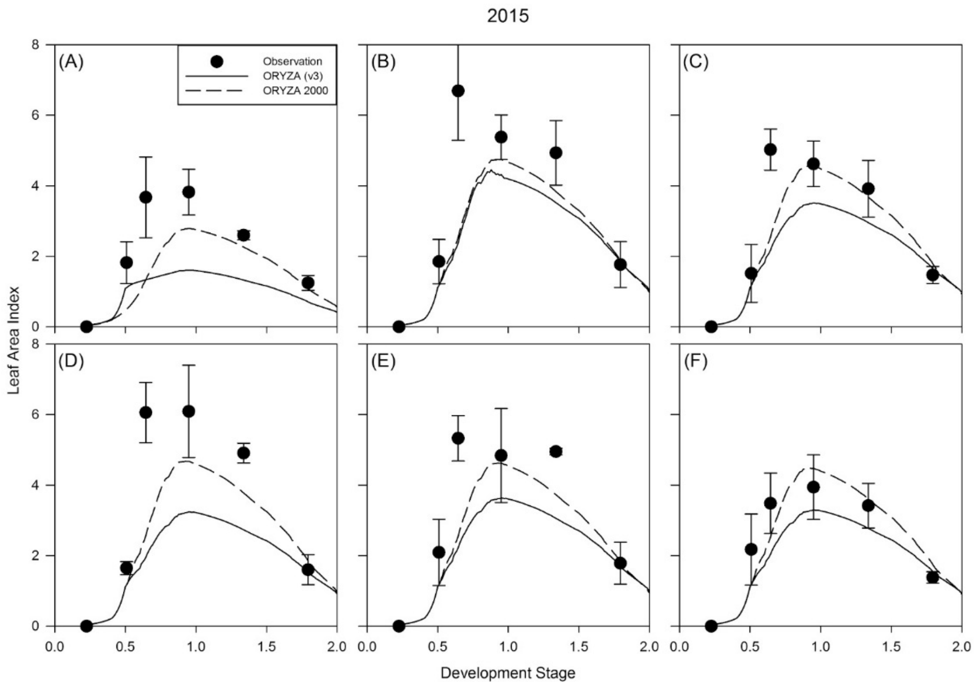
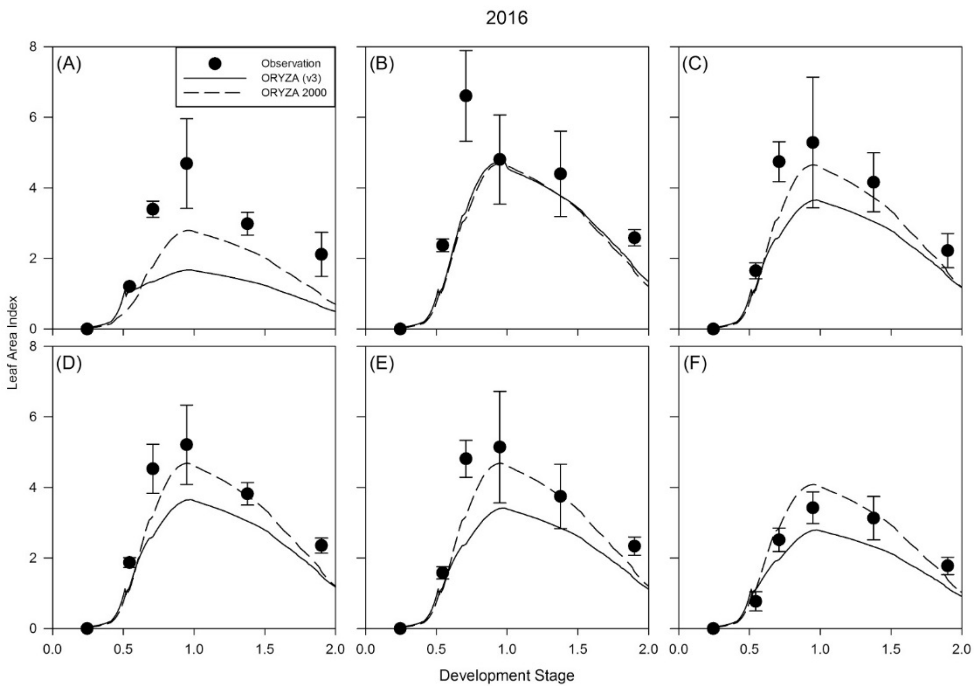


Fig. C4. Daily output of panicle weight from 2015 to 2017.


2015
(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Leaf Area Index
Development Stage
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0


2016
(A)
(B)
(C)
(D)
(E)
(F)
Observation
ORYZA (v3)
ORYZA 2000
Leaf Area Index
Development Stage
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0

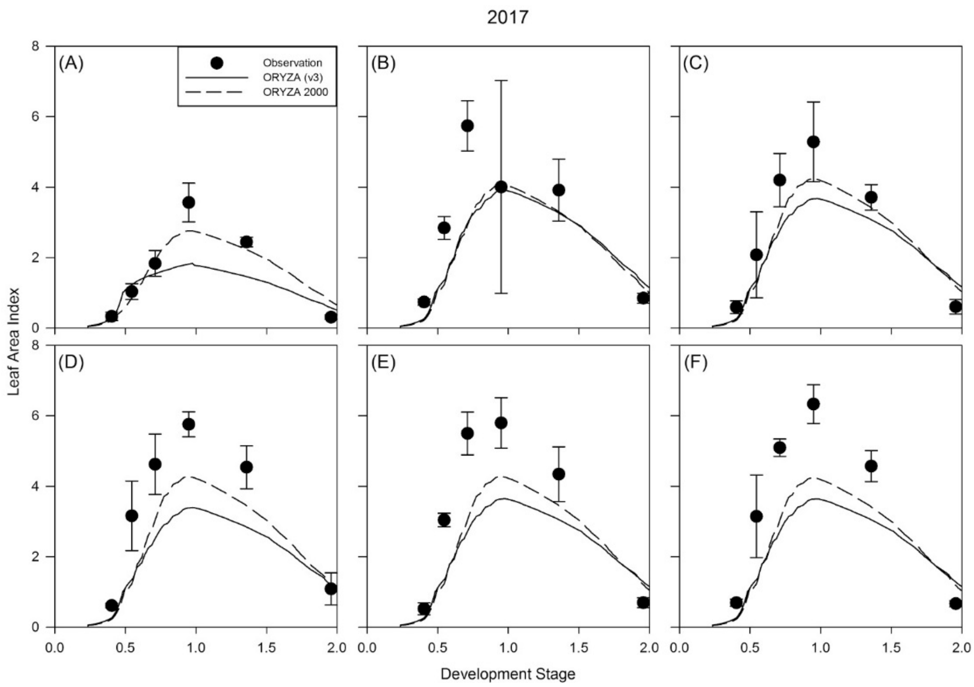


Fig. C5. Daily output of leaf area index from 2015 to 2017.

초 록

최근 집약농업으로 인한 환경문제가 생기면서 지속가능한 농업에 대한 관심이 증가하고 있으며, 그 중 한 가지 방법인 유기농업에도 관심이 증가하고 있다. 유기농업에서 결정하기 어려운 시비처리를 최적화하기 위해 작물생육과 토양양분동태를 모두 모의할 수 있는 작물모델들을 사용할 수 있으나, 현재까지 유기질비료 시용조건에서의 작물 생육모의에 관한 연구는 적게 이루어져왔다. 본 연구에서는 ORYZA 모델을 기반으로 한 ORYZA 2000 모델과 ORYZA (v3) 모델을 사용하여 유기질비료 시용조건에서의 벼 생육을 모의하고, 유기질비료의 시비처리를 최적화 하기에 적합한 모델을 탐색하였다. 검증을 위한 자료를 수집하기 위해 국립농업과학원의 실험포장과 순천의 실제 농가에서 2015 년부터 3 년에 걸쳐 유기농 조건에서 실험을 진행하였다. 입력자료는 실제 재배관리, 토양 측정자료 및 토양통자료, 농업기상정보 및 기상청의 기상자료를

사용하였으며, Lee et al. (2015)의 품종모수를 사용하였다. 모의 결과 두 모델 모두 토양 무기태질소를 예측하는 데에는 한계가 있었다. 질소 흡수의 경우 생육 전반적으로 과소추정 되었으며, 이에 따라 작물 생육도 관측값보다 낮게 모의되었다. 화학비료처리에 대해서는 차이가 작게 나타났으나 그 외의 처리에서는 모델 간 차이가 크게 나타났으며, 특히 질소흡수가 상대적으로 높게 나타난 ORYZA (v3) 모델에서 오히려 ORYZA 2000 모델보다 낮은 생육양상을 보였다. 수량의 경우 ORYZA (v3) 모델보다 ORYZA 2000 모델에서 비교적 실제 수량과 비슷하게 모의되었다. 토양 질소 및 질소흡수의 오차는 유기질비료의 무기화 과정에서 큰 차이를 보였을 것으로 예상되었다. 또한, 토양통자료와 기상자료의 실제 포장과의 차이 및 품종모수와 실제 품종의 차이로 인해 오차가 생겼을 것으로 예상되었다.